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ABSTRACT

One aspect of Jean Piaget's theory of intellectual development is presented and its implications for designing and using homework problems is discussed. Suggested is a way in which homework problems can be used to provide students an opportunity for self-regulation. Also discussed are the deficiencies of typical homework problems and examples are provided which can initiate self-regulation. Self-regulation is defined as the spontaneous but gradual process of seeking a coherence of ideas with observations, and of ideas with other ideas in Piagetian terms, integrating concepts into larger conceptual frameworks. Homework problems suggested to aid the student in self-regulation should include open-ended problems, problems with an apparent paradox, record keeping of the students' various ideas (successful or not), should require the students to draw diagrams of the problem, and the problems should require the student to search for data to solve the problems. (Author/DS)

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PHYSICS PROBLEMS AND THE PROCESS OF SELF-REGULATION

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PHYSICS PROBLEMS AND THE PROCESS OF SELF-REGULATION

In two previous articles ["Piagetian Theory and Instruction in Physics," Phys. Teach. 11, 165 (1973) and "Promoting Intellectual Development Through Science Teaching," Phys. Teach. 11, 273 (1973)] Jean Piaget's theory of intellectual development and its general implications for physics teaching were discussed. The purpose of this note is to examine more closely one aspect of that theory and discuss its implications for designing and using homework problems. We will briefly describe the process of self-regulation (the process Piaget hypothesizes governs all intellectual growth) and suggest a way in which homework problems can be used to provide students an opportunity for self-regulation. Further, we will discuss deficiencies of typical homework problems and provide a number of example problems which we believe can initiate self-regulation. Through the process of self-regulation initiated by thought-provoking problems, we believe students will not only be able to develop meaningful understandings of the concepts involved but will also progress from relatively concrete (or limited) to more abstract or generalizable modes of thinking.

The Process of Self-Regulation

The process by which Piaget hypothesizes that patterns of reasoning are refined, extended, or combined with other patterns of reasoning is called self-regulation. Initially, basic reasoning patterns serve to guide an individual's actions within his surroundings. As long as those actions promote satisfactory interaction, the basic patterns continue to guide behavior. However, owing to the individual's extended interaction with his environment he meets contradictions i.e., situations for which his initial patterns of reasoning do not serve as effective guides to behavior. These contradictions produce a state of disequilibrium. In other words, his patterns of reasoning are found wanting and must somehow be changed. If the disequilibrium (i.e., the incompatability between the present reasoning patterns and the new situation) is not too great, he will spontaneously begin to alter his patterns of reasoning in an attempt to assimilate the new situation. The process by which an individual actively seeks to reestablish equilibrium is termed self-regulation. The altered reasoning patterns which develop are then tried. If the patterns guide behavior successfully so that the person's efforts obtain positive feedback the patterns are reinforced. Continued positive feedback then produces an increasingly stable set of reasoning patterns. In this manner the person gradually builds new reasoning patterns (i.e., develops new understandings) and adapts to new situations.

Homework Problems as Initiators of Self-Regulation

Self-regulation then can be viewed as the spontaneous but gradual process of seeking a coherence of ideas with observations, and of ideas with other ideas. In particular, the refinement of concepts and especially their integration into larger conceptual frameworks (an aspect of refinement) are described by Piaget as coming about through self-regulation. This gradual process of reestabishing equilibrium through self-regulation affords the possibility of intitiating interactions between students and subject matter

with the use of homework problems provided the following two factors are present: (1) Problems must be chosen so that the student can partially, but not completely assimilate them to old ideas (i.e., a moderate state of disequilibrium must result from the problem), and (2) sufficient time must be allowed for the student to grapple with the new situation, possibly with appropriate "hints" to direct his thinking, but allowing him to put the ideas together himself.

An important facet then in selecting problems which encourage self-regulation is to obtain a careful match between what the student knows and the kind of problem he is asked to work through. The ideal situation would seem to be one in which the problems are challenging but are felt to be solvable. The hypothesis is that a challenging but solvable problem will place a student into an initial state of disequilibrium. However, through his own efforts at bringing together what he has done in the laboratory, read in the textbook, heard in lectures, learned from other past experiences, and obtained from teacher and/or peer discussions he will gradually organize his thinking about this information and successfully solve the problem. This success then will establish a new and more stable equilibrium. This new state of equilibrium will be one with increased understanding of the subject matter and increased problem-solving capability. Prior to providing, examples of the kind of problems we believe can initiate self-regulation a few comments will be made regarding deficiencies of standard homework problems.

Deficiencies of Typical Homework Problems and Characteristics of Problems to Encourage Self-Regulation

Typical homework problems seldom require a student to examine his own thinking, make comparisons and raise questions which, in fact, are crucial to scientific inquiry. These problems usually require students to apply an equation or sometimes two or three equations to obtain a solution. Students quickly come to realize that the name of this game is "Can you discover the correct equation?" This is a game of recognition--a sort of high order matching process involving little thought. Although this process can be an important one, we believe that little if any self-regulation takes place in this way. Lacking from typical homework problems is the need to think about:

1. The data of the problem. Usually there is just the right amount, no more or less, whereas in reality there is either a dearth or superfluity of information and the problem is to discover what is relevant.

2. The approach to the problem. Usually this is determined by the chapter heading. If, for example, a mechanics problem can be solved either by Lagrange's equations, Newton's laws, or energy conservation, the choice is dictated by irrelevant considerations, e.g., the problem comes from the chapter on Lagrange's equations. It is important for students to learn that many approaches may seem reasonable and the problem is to decide whether one is particularly appropriate.

3. The (tacit) assumptions of a problem-solving strategy (e.g., deciding between use of Boyle's Law or the Vander Waals' equation). This decision is usually made <u>for</u> the student, not by the student.

4. The physical arguments involved in the problem as opposed to the mathematical ones. Too often problems are only exercises in using mathematical tools (a necessary exercise) without ever demanding that the student try to either arrive at or qualitatively justify the mathematical result by physical (phenomenal) arguments utilizing both principles and order of magnitude calculations. Indeed, the physical or intuitive argument often precedes the mathematical in actuality.

5. The statement of a problem. Problems are tailored to fit the text when, in fact, the real problem is conceptualizing a real situation in terms of a model, i.e., doing the tailoring. This involves all of the above points.

A few points should be kept in mind when designing, discussing, using, and scoring problems which attempt to encourage self-regulation:

1. Open-ended problems (problems with no single solution) are often excellent tools to encourage thinking.

2. Problems which present an apparent paradox produce disequilibrium and can initiate self-regulation. Paradox problems by their nature are generally short and incisive. Leighton (1964) in his forward to the exercise workbook written to accompany The Feynman Lectures in Physics discussed the kinds of problems which appeared most suitable to him. He suggested that problems of a kind that are numerically or analytically simple, yet incisive and illuminating in content were particularly useful.

3. To encourage self-regulation it is often helpful to ask students to keep a record of and hand in all the various ideas they tried out and found unsuccessful as well as the ones which were successful in arriving at the problem solution. Discussions of these steps in an atmosphere in which these ideas are recognized not only as worthwhile but as necessary, clue students into the fact that "real" problems should and indeed must involve a certain amount of trial and error, albeit informed trial and error.

4. Have the students search for necessary data so they examine their conceptualization of the problem. Either give superfluous data or omit necessary data. To account for the latter, students should have to make plausible assumptions or introduce suitable symbols for quantities that are needed to solve the problem.

5. Require students to draw a diagram of the physical situation. To do this, students have to think deeply about the spatial relationships of the interacting objects, and may find discrepancies as they compare their preconceptions with the diagram.

6. Provide for a "problem clinic" or tutorial service where students can get help with problems while they are solving them, and before they have to be turned in. Interaction with other persons can be very helpful and is often even necessary if students are to conceptualize, then critically analyze their own thinking.

7. For problems designed to engage a student over a period of, say, two weeks, the teacher should consult with the student several times in order to:

   a. Discuss with him his initial approach. If this approach is reasonable but known in advance to be inappropriate, the teacher should not intervene at this point, but rather he should let the student discover for himself why the approach will not work.

   b. Discuss with the student alternative approaches both when the initial approach is appropriate and when it is reasonable but not appropriate. In either case, let the student first discover which approach will work. Then discuss alternatives, even if the first approach worked. It may be that he will accept inappropriate alternatives as reasonable. He may then discover on his own why they are not.

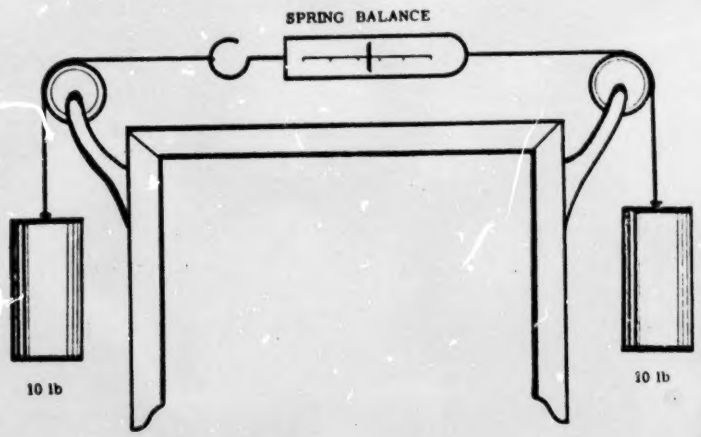
   c. Discuss both semi-quantitative (order of magnitude) and qualitative arguments anticipating the outcome of more rigorous approaches. Limiting cases should be used as a check when solutions to simpler problems are already known.

   d. Discuss alternatives to an inappropriate and time-consuming approach. This is to avoid having the student spend too much time discovering the inadequacies of an approach. Overall, the student should get from the teacher a feeling for the general considerations appropriate to choosing and comparing strategies, i.e., a feeling for the process of inquiry.

8. Although solutions (numerical or algebraic) should be provided for all problems (not just the "odd-numbered" ones), students must understand that a premature glance at a solution will surely affect their conception of the problem and distort the problem solving procedure. Knowledge of the solution can provide stimulating feedback after the student has completed and carried through a formulation of a solution.

Problem One

Since the net force on the spring scale shown in Figure 1 is zero how can the scale register a non-zero reading? What does the scale register? Why isn't it 20 since it is pulled by 10 lbs. at each end?

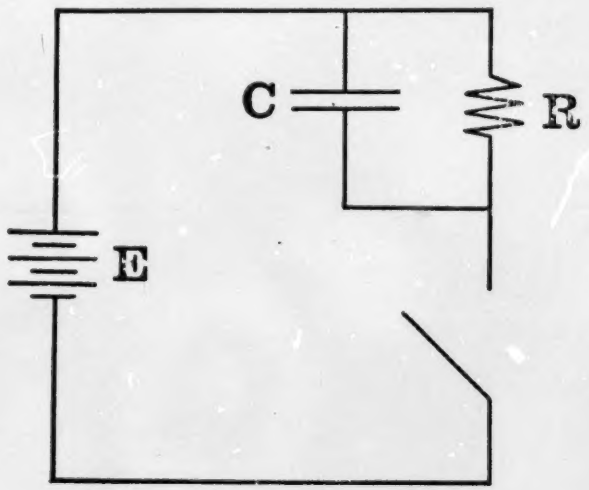


Comment:

This example illustrates how a little knowledge can go a wrong way. At first, concepts are only vaguely grasped and thus over-extended. Here we obviously have two forces equal to zero and yet the scale does not read zero. Or, we have each force contributing 10 lbs. of tension to the scale to give 20 lbs. These two approaches use unrestricted (over-extended) concepts which must be coordinated, via self-regulation, with other concepts, e.g., free-body diagrams and action-reaction, in order to resolve the discrepancy.

Problem Two

A capacitor and resistor are connected in a circuit as shown in Figure 2. The values are C = 250 μf, R = 10,000 ohms, and E = 400 volts. Initially the switch is closed, and then it is opened suddenly. Use two methods to find the energy dissipated in the resistor after the switch is opened. Do both methods give the same result? Should they give the same result? If so, why? If not, why not?



Comment:

This problem calls for two quantitative analyses of the same situation. If the student is able to readily think of two methods of solution and obtain the same answer using both methods no disequilibration will result. However, if two different answers are obtained the student should check his own work. The discrepancy could be resolved quickly if the source of the difference was an error in calculation. If, however, the difference was due to difficulty in conceptualization, then the check will promote self-regulation.

Problem Three

The gas kinetic temperature in the upper atmosphere is about 1000°K. The temperature at the surface of a burning match is about the same. Yet a person would be very cold in the upper atmosphere. How can that be?

Comment:

This problem presents a paradox because 1000°K suggests extreme heat and yet it is "cold up there." Resolution through self-regulation leads to a more scientific and less everyday notion of the relation between temperature and heat.

Problem Four

A glass is exactly full of water at 0°C and has a cube of ice floating in it. When the ice melts (still at 0° C) the water will not overflow, because the ice displaced water equal to the water it is composed of. OK. Let us look at some fine points. In what direction (slight overflow or the opposite) would each of the following affect the result? Give only the direction.

(a) The ice cube contained some grains of sand.

(b) The ice cube contained some air bubbles.

(c) The water (and the glass) were not at 0° to start with, but were at room temperature.

(d) The "water" is not water at all, but is a Martini, which is close to 0° but, due to its alcoholic content has density less than that of water.

Comment:

This problem originally appeared in an article by Richard Crane ["Problems for Introductory Physics," Phys. Teach. 7, 371 (1969)]. It as well as other problems in that article (e.g., problems 8, 17, 18, 26-29) are excellent examples of problems which will promote self-regulation. Problems 34, 41, 42, and 48 which appeared in a second article by Crane [Phys. Teach. 8, 182 (1970)] also are thought provoking and should encourage self-regulation.

Problem Five

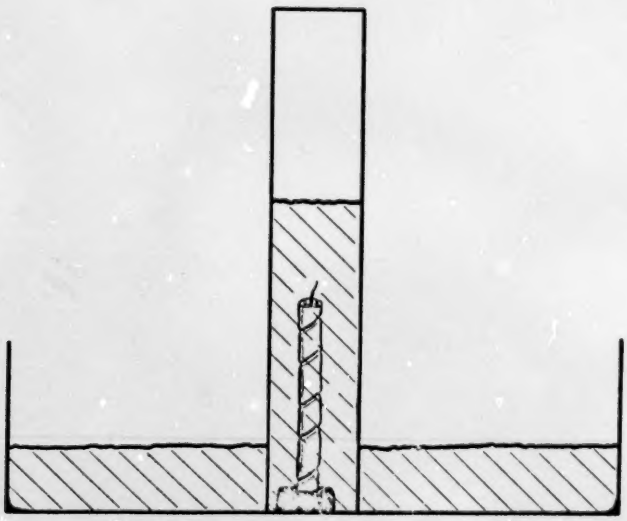
If heat is simply molecular motion, what is the difference between a hot, stationary golf ball sitting on a tee and a cold rapidly moving one.

Comment:

Of course, heat is not simply molecular motion unless you specify random motion. Thus, self-regulation refines or sharpens a global or relatively diffuse concept. It is typical of students that they only assimilate parts of a concept at first. By provoking them to discover or recover all the parts, the concept becomes more sharply defined.

Problem Six

When a cylinder, open at one end, is placed over a burning candle which is sitting in a container of water (see Figure 3 below) the candle flame goes out and water rises into the cylinder. Why does the flame go out and why does the water rise? Note: Not all observations are mentioned in the description. What other observations do you think you would make if the phenomenon was observed? Obtain the necessary materials and try the experiment yourself. Try the experiment varying the number of candles used, the amount of water in the container, the size and shape of the cylinder, the speed with which you place the cylinder over the candle, and anything else you can think of.



Comment:

This problem is one which often yields a quick but erroneous solution. Most students will hypothesize that the candle goes out because it burned up all the oxygen in the cylinder and the water then came in to replace the oxygen. Selected items of information or questions could be supplied at this point to provoke students to abandon this idea and continue their search. For example: What is produced when a flame consumes oxygen? Two burning candles make more water rise than one. Small bubbles were observed escaping from the bottom of the cylinder. Why might this have occurred? These observations contradict the initial explanation and should provoke disequilibrium. Once other explanations are offered they can be analyzed to determine their suitability. They may lead some students to try the experiment to collect further data. Explanations can then be evaluated in terms of their compatibility with the data and their compatibility with physical conceptions.

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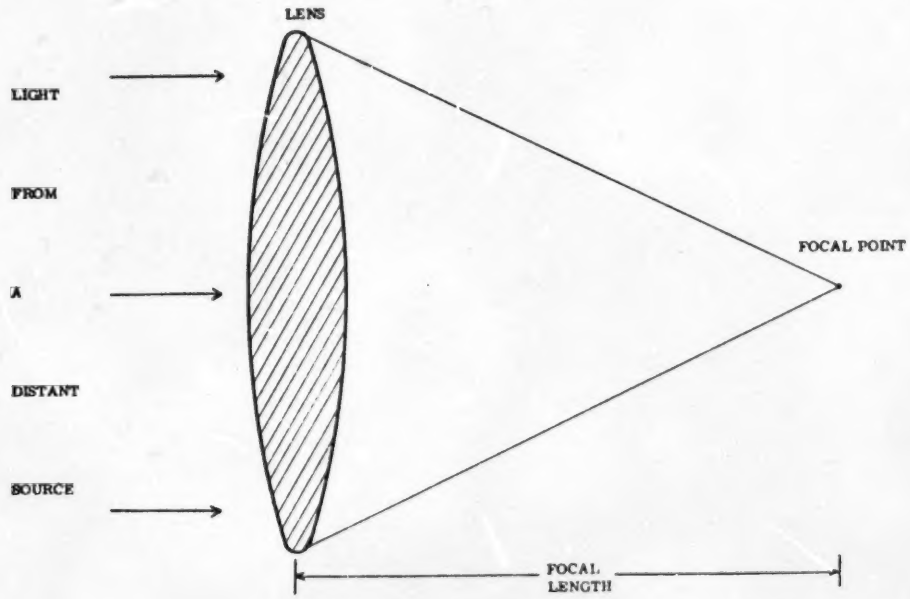
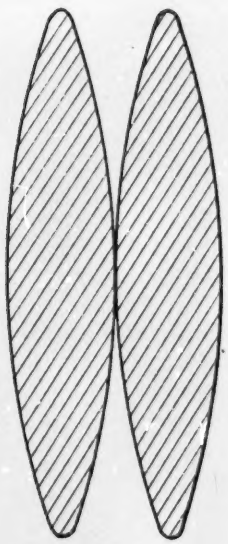
(c) Now check your two equations. Are they the same? Do you think they should be the same. If so why? If not, why not? If you believe they should be the same but you have two different equations rethink the problem and try to reduce the two situations to one equation.





Comment:

Students will generally solve parts (a) and (b) with little difficulty. However, they will seldom write an equation general enough to account for both situations. The suggestion in part (c) that the equations should be the same and the student's intuitive feeling that a general equation could be found, coupled with the original incompatible equations should produce disequilibrium and provoke the student to rethink the problem.

Problem Eleven

A student measures his weight by climbing onto the large platform of a big spring scale. He takes a step to one side and notices that just as he started to do this, the scale registered less than his weight. Before he could puzzle this through, he noticed that just as he completed the step, the scale now registered more than his weight. If there is nothing wrong with the scale, then what was going on?

Comment:

"Weight is weight is weight," a famous poet might have said. So how can a scale read less than one's weight. Worse, how can it also read more? Still worse, if it isn't the scale that must be fixed, then how am I, the student, to fix my ideas?

Problem Twelve

A brick is supported by a string A from the ceiling, and another string B is attached to the bottom of the brick. If you give a sudden jerk to B it will break, but if you pull on B steadily, A will break. Since the force is the same both ways how could this occur?

Comment:

Since the student is used to thinking in a-temporal terms, he will think that force is force and so equal forces have equal effects. So how can the string break in one instance and not in the other? Again, common sense is in conflict with observation and this use of physics to set the world straight is likely to be retained.

Acknowledgment

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